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TITLE: SYSTEM AND METHOD FOR CONTROLLING
 A BRAKE MOTOR

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5 SYSTEM AND METHOD FOR CONTROLLING A BRAKE MOTOR

FIELD OF THE INVENTION

10 The technical field of this disclosure is brake systems, and more particularly, electric brake systems and electric brake systems within hybrid brake systems.

BACKGROUND OF THE INVENTION

Control of brake systems is an important aspect of automotive functionality.

15 Brake systems must engage when required, such as, for example during application of caliper pressure to slow or stop a vehicle. Additionally, brake systems must remain unengaged when not required. The vehicle will not be able to function as designed if brake systems, or portions of brake systems, function improperly. One cause of brake system failure is excessive heat.

20 Recently, hybrid brake systems have become increasingly utilized in the automotive industry. Hybrid systems typically utilize a hydraulic brake system for one axel (i.e. the front axel) and an electric or electro-mechanical brake system for the other axel. Additionally, electric or electro-mechanical only brake systems have become increasingly utilized in the automotive industry as well.

25 In electric or electro-mechanical brake systems, temperature sensing is a critical issue to protect the motor and electronics of the electric caliper. Currently, temperature sensing activity in the industry is centered around a temperature sensor mounted on the main circuit board, such as, for example the controller circuit board. Unfortunately, the circuit board is not the only critical thermal element within electric or electro-mechanical
30 brake systems.

The present invention advances the state of the art in controlling brake motors

SUMMARY OF THE INVENTION

One aspect of the invention includes a method for controlling a brake motor by receiving brake motor information, determining a first brake motor voltage value and a
5 brake motor current value based on the motor information when the brake motor is active, determining a brake motor resistance value based on the first brake motor voltage value and the brake motor current value, determining a brake motor temperature value based on the determined brake motor resistance value, and producing a brake motor control signal based on the determined brake motor temperature value.

10 In accordance with another aspect of the invention, a computer readable medium storing a computer program includes: computer readable code for determining a first brake motor voltage value and a brake motor current value based on motor information when a brake motor is active; computer readable code for determining a brake motor resistance value based on the first brake motor voltage value and the brake motor current
15 value; computer readable code for determining a brake motor temperature value based on the determined brake motor resistance value; and computer readable code for producing a brake motor control signal based on the determined brake motor temperature value.

In accordance with yet another aspect of the invention, a system for controlling a brake motor is provided. The system includes means for receiving brake motor
20 information. The system additionally includes means for determining a first brake motor voltage value and a brake motor current value based on the motor information when the brake motor is active. Means for determining a brake motor resistance value based on the first brake motor voltage value and the brake motor current value is provided. Means for determining a brake motor temperature value based on the determined brake motor
25 resistance value and means for producing a brake motor control signal based on the determined brake motor temperature value is also provided.

The foregoing and other features and advantages of the invention will become further apparent from the following detailed description of the presently preferred embodiment, read in conjunction with the accompanying drawings. The scope of the invention is defined by the appended claims and equivalents thereof, the detailed description and drawings being merely illustrative of the invention rather than limiting the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

10 **FIG. 1** is a block diagram illustrating a brake motor control system according to an embodiment of the present invention;

FIG. 2 is a schematic diagram illustrating a voltage sensing apparatus according to an embodiment of the present invention;

15 **FIG. 3** is a schematic diagram illustrating a current sensing apparatus that may be utilized with the method of the invention; and

FIG. 4 is a flow diagram illustrating a method for controlling a brake motor according to an embodiment of the present invention.

20 Throughout the specification, and in the claims, the term “connected” means a direct connection between components or devices that are connected without any intermediate devices. The term “coupled” means either a direct connection between components or devices that are connected, or an indirect connection through one or more passive or active intermediary devices.

DETAILED DESCRIPTION OF THE
PRESENTLY PREFERRED EMBODIMENT

FIG. 1 is a block diagram illustrating a brake motor control system **100**. **FIG. 1**
5 details an embodiment of a system for controlling a brake motor **110** within a brake
system in accordance with the present invention. Brake motor control system **100**
includes brake motor **110** and brake motor controller **120**. Brake motor **110** includes
motor shaft **115** coupled to brake motor **110**. Brake motor controller **120** includes
voltage sensor **130**, current sensor **140**, processor **150**, and power motor driver **160**.
10 Brake motor control system **100** may include additional components not relevant to the
present discussion.

In one embodiment and illustrated in **FIG. 1**, brake motor **110** is implemented as
a three-phase direct current (DC) motor, which is a commonly known and utilized
technology in the motor industry. In other embodiments, brake motor **110** is
15 implemented as a direct current (DC) brush-type motor or multi-phase motors, such as,
for example a 4-phase switched reluctance motor. In **FIG. 1**, brake motor **110** includes
three phase stator winding inputs (e.g. terminals) (PhAin, PhBin, and PhCin) and motor
shaft **115**. Brake motor **110** may include additional components not relevant to the
present discussion.

20 Brake motor controller **120** is a composite assembly that provides motor control
functions, such as, for example motor sensing, speed estimation, rotor location
information, and motor drive control. Brake motor controller **120** is any suitable device
capable of providing motor control functions. Brake motor controller **120** typically
includes a microcontroller, a processor, a combination of a microcontroller and processor,
25 software modules for performing motor control functions, hardware modules for
providing brake motor information, and volatile or non-volatile memory. Brake motor
controller **120** may include additional components not relevant to the present discussion.
Brake motor controller **120** may be implemented as any suitable brake motor controller
as is commonly known technology in the motor control industry. In one embodiment
30 and referring to **FIG. 1**, brake motor controller **120** includes voltage sensor **130**, current

sensor **140**, processor **150**, and power motor driver **160**. In another embodiment, voltage sensor **130** and current sensor **140** are located elsewhere within brake motor control system **100** and in communication with brake motor controller **120** and processor **150**.

5 Power motor driver **160** is a motor control element that receives instructions from processor **150** and provides control signals to brake motor **110**. Power motor driver **160** additionally provides brake motor information such as, for example brake motor voltage information and brake motor current information to sensors located within brake motor control system **100**. Power motor driver **160** includes power input terminal Pwr, control
10 input/output terminal CTL1, current output terminal I1, voltage output terminal V1, and output control phase terminals (PhAout, PhBout, and PhCout). Current output terminal I1 and voltage output terminal V1 provide brake motor information. In one embodiment and described in **FIG. 2** below, voltage output terminal V1 includes three signal outputs with each signal output coupled to an output control phase terminal (PhAout, PhBout,
15 and PhCout) and providing phase voltage information. In this embodiment and described in **FIG. 3** below, current output terminal I1 includes a signal output providing DC motor current information. In another embodiment, current output terminal I1 includes three signal outputs with each signal output coupled to an output control phase terminal (PhAout, PhBout, and PhCout) and providing link current information.

20 Voltage sensor **130** is a voltage sensing apparatus that includes voltage input terminal V2 and voltage output terminal V3. Voltage sensor **130** is further described in **FIG. 2**, below. Voltage input terminal V2 is coupled to voltage output terminal V1 of power motor driver **160**. Voltage sensor **130** receives phase voltage information from power motor driver **160** and provides scaled analog voltage information to processor **150**
25 via voltage output terminal V3.

Current sensor **140** is a current sensing apparatus that includes current input terminal I2 and current input/output terminal I3. Current sensor **140** is further described in **FIG. 3**, below. Current input terminal I2 is coupled to current output terminal I1 of power motor driver **160**. In one embodiment, current sensor **140** receives link current information from power motor driver **160** via current input terminal I2 and sensor control signals from processor **150** via input/output terminal I3, samples the link current, and provides scaled motor current information to processor **150** via input/output terminal I3. In another embodiment, current sensor **140** receives link current information via current input terminal I2 and provides scaled link current information to processor **150** via input/output terminal I3.

Processor **150** includes control input/output terminal CTL2, control input terminal (Input), voltage sensor input terminal VSen, and current sensor input terminal ISen. Control input/output terminal CTL2 is coupled to control input/output terminal CTL1 of power motor driver **160**, voltage sensor input terminal VSen is coupled to voltage output terminal V3 of voltage sensor **130**, and current sensor input terminal ISen is coupled to current input/output terminal I3 of current sensor **140**. Processor **150** may include additional components not relevant to the present discussion. Processor **150** receives a system control signal via control input terminal (Input), such as, for example to activate brake motor **110** or to deactivate brake motor **110**. When processor **150** receives a system control signal to activate brake motor **110** and brake motor information from voltage sensor **130** and current sensor **140**, processor **150** produces a brake motor control signal, such as, for example a pulse-width modulated control signal that is applied to brake motor **110** for torque production.

In operation, power motor driver **160** receives power from power input terminal Pwr and a control signal from control input/output terminal CTL1, such as, for example a pulse-width modulated (PWM) control signal. Power is applied to a three-phase winding within brake motor **110** based on the control signal thereby powering the brake motor **110** and the coupled motor shaft **115**. Power motor driver **160** produces brake motor information that is dependent on conditions present within brake motor **110** and provides

the brake motor information to voltage sensor **130** and current sensor **140**. Phase voltage information is provided to voltage sensor **130** at voltage output terminal V1 of power motor driver **160**. Link current information is provided to current sensor **140** at current output terminal I1 of power motor driver **160**.

FIG. 2 is a schematic diagram illustrating a voltage sensing apparatus **200**. In one embodiment and illustrated in **FIGS. 1** and **2**, voltage sensing apparatus **200** senses voltage from brake motor **110** that is implemented as a three-phase direct current (DC) motor. In other embodiments, voltage sensing apparatus **200** senses voltage from brake motor **110** that is implemented as a direct current (DC) brush-type motor or multi-phase motors, such as, for example a 4-phase switched reluctance motor. Voltage sensing apparatus **200** includes three single-phase voltage inputs (Aout, Bout, and Cout) and three single-phase voltage outputs (DiagphA, DiagphB, and DiagphC). Each single-phase voltage input has an associated single-phase voltage output (e.g., Aout and DiagphA). In one embodiment and referring to **FIG. 1** above, voltage sensing apparatus **200** is implemented as voltage sensor **130**. In this embodiment, three single-phase voltage inputs (Aout, Bout, and Cout) are received at voltage input terminal V2 and three single-phase voltage outputs (DiagphA, DiagphB, and DiagphC) are produced at voltage output terminal V3.

Voltage sensing apparatus **200** provides a step-down analog voltage at each single-phase voltage output (DiagphA, DiagphB, and DiagphC) when the voltage source is active, referred to as a stall condition. Voltage information in the form of a PWM motor driver voltage signal is received at each of the three single-phase voltage inputs (Aout, Bout, and Cout) and is passed through a voltage divider to scale the voltage for use by a processor. The scaled voltage is passed through a low pass filter for removal of the high frequency PWM portion of the analog voltage signal and provide a DC analog voltage to the processor which is proportional to motor voltage. A diode pair is provided for over-voltage protection.

In one embodiment, a PWM voltage signal received at single-phase voltage input Aout is passed through the voltage divider of resistors (R133 and R206) to scale the voltage. In an example, the voltage divider of resistors (R133 and R206) is implemented as resistors having values of 10.0 kilo-ohms and 4.02 kilo-ohms respectively. In this
5 embodiment, the scaled voltage is passed through low pass filter (C137) to single-phase voltage output DiagphA. In an example, low pass filter (C137) is implemented as a 0.1 microfarad capacitor. Additionally in this embodiment, diode pair (D11) is provided for over-voltage protection. In an example, diode pair (D11) is implemented as MMBD
10 1203 diode that is an industry standard diode available from major silicon manufactures. Diode pair (D11) is a single part that contains both diodes in a single package. Alternatively, diode pair (D11) can be implemented as two individual diodes utilizing a similar configuration.

Similarly, a PWM voltage signal received at single-phase voltage input Bout is
15 passed through the voltage divider of resistors (R131 and R207) to scale the voltage. In an example, the voltage divider of resistors (R131 and R207) is implemented as resistors having values of 10.0 kilo-ohms and 4.02 kilo-ohms respectively. In this embodiment, the scaled voltage is passed through low pass filter (C138) to single-phase voltage output DiagphB. In an example, low pass filter (C138) is implemented as a 0.1 microfarad
20 capacitor. Additionally in this embodiment, diode pair (D13) is provided for over-voltage protection. In an example, diode pair (D13) is implemented as MMBD 1203 diode that is an industry standard diode available from major silicon manufactures. Diode pair (D13) is a single part that contains both diodes in a single package. Alternatively, diode pair (D13) can be implemented as two individual diodes utilizing a
25 similar configuration.

Additionally, a PWM voltage signal received at single-phase voltage input Cout is passed through the voltage divider of resistors (R129 and R208) to scale the voltage. In an example, the voltage divider of resistors (R129 and R208) is implemented as resistors having values of 10.0 kilo-ohms and 4.02 kilo-ohms respectively. In this embodiment, the scaled voltage is passed through low pass filter (C139) to single-phase voltage output DiagphC. In an example, low pass filter (C139) is implemented as a 0.1 microfarad capacitor. Additionally in this embodiment, diode pair (D15) is provided for over-voltage protection. In an example, diode pair (D15) is implemented as MMBD 1203 diodes that is an industry standard diode available from major silicon manufactures. Diode pair (D15) is a single part that contains both diodes in a single package. Alternatively, diode pair (D15) can be implemented as two individual diodes utilizing a similar configuration.

Further, voltage sensing apparatus **200** provides a closed-loop motor diagnostic voltage at each single-phase voltage output (DiagphA, DiagphB, and DiagphC) when the voltage source (e.g. brake motor) is inactive. When the voltage source is inactive, a closed circuit is created across the three single-phase voltage inputs (Aout, Bout, and Cout) by the low impedance of the motor stator windings resulting in current flowing from an internal voltage supply V+ to ground GND. The current flows through resistors (R118, R135, and R136) and settles at a specific value, depending on the value of resistors (R118, R135, and R136) and the voltage value supplied from internal voltage supply V+, and is referred to as the closed-loop motor diagnostic voltage value. In one embodiment and referring to **FIG. 1** above, voltage sensing apparatus **200** is implemented as voltage sensor **130**. In this embodiment, the closed-loop motor diagnostic voltage value is produced at voltage output terminal V3 of voltage sensor **130**.

FIG. 3 is a schematic diagram illustrating a current sensing apparatus **300** that may be utilized with the method of the invention. Current sensing apparatus **300** illustrates one possible embodiment of circuitry to measure motor current of a brake motor, such as, for example as described in patent number 6,262,544 B1 issued on July 17, 2001 and titled FOUR QUADRANT MOTOR OPERATION USING DC BUS CURRENT SENSING. In one embodiment and illustrated in **FIGS. 1** and **3**, current sensing apparatus **300** senses current from brake motor **110** that is implemented as a three-phase direct current (DC) motor. In other embodiments, current sensing apparatus **300** senses current from brake motor **110** that is implemented as a direct current (DC) brush-type motor or multi-phase motors, such as, for example a 4-phase switched reluctance motor. In one embodiment and referring to **FIG. 1** above, current sensing apparatus **300** is implemented as current sensor **140**.

In operation, current sensing apparatus **300** receives a DC link current (ISense) from a brake motor at node N31. A motor driver bridge portion of current sensing apparatus **300** includes current sense resistors (R104 and R105). The motor driver bridge portion of current sensing apparatus **300** provides input to amplifier U6B at nodes (N32 and N33). Resistors (R108 and R112) provide input impedance for amplifier U6B. In one embodiment, current sense resistors (R104 and R105) are implemented as .01 ohm resistors and resistors (R108 and R112) are implemented as 3.83 kilo-ohm resistors.

A DC offset portion of current sensing apparatus **300** includes voltage input VR+ and capacitor (C101). The DC offset portion of current sensing apparatus **300** provides a DC offset at node N36. In one embodiment, capacitor (C101) is implemented as a 0.1 microfarad capacitor. In this embodiment, voltage input VR+ provides a 2.5 volt DC offset at node N36.

An amplifier portion of current sensing apparatus **300** includes amplifier U6B, resistors (R113, R107, R108, and R112) and capacitors (C106 and C116) configured as a differential amplifier. Amplifier U6B amplifies the current sense signal to a level that
5 can be utilized by a microprocessor analog-to-digital (A/D) input at node N34. In one embodiment, amplifier U6B is implemented as an MC33072 amplifier that is an industry standard amplifier available from major chip manufactures. In this embodiment, resistors (R107 and R113) are implemented as 24.9 kilo-ohm resistors and capacitors (C106 and C116) are implemented as 47 picofarad capacitors. In this embodiment, resistors (R107
10 and R113) are of equal value and resistors (R108 and R112) are of equal value. The gain of the amplifier is equal to the ratio of resistors (R113 and R112) expressed as $R113/R112$.

A sample and hold switch portion of current sensing apparatus **300** includes sample and hold voltage input (S/H), voltage input V+, transistor Q24, resistors (R111,
15 R115, and R116), voltage input VR+, and capacitor C125. The sample and hold switch portion of current sensing apparatus **300** provides a control voltage at node N35 that controls a sample and hold portion of current sensing apparatus **300**. In one embodiment, transistor Q24 is implemented as an MMBT100 transistor that is an industry standard transistor available from major silicon manufactures. In this embodiment, resistors
20 (R111, R115, and R116) are implemented as 4.99 kilo-ohm, 10.0 kilo-ohm, and 10.0 kilo-ohm respectively. Capacitor C125 is implemented as a 0.1 microfarad capacitor.

The sample and hold portion of current sensing apparatus **300** includes transistors (Q22 and Q23), resistor R110, capacitor C115, and sampled motor current signal output IFBK. Transistors (Q22 and Q23) provide a sample and hold function and capacitor
25 C115 stores the sampled motor current signal. The sampled motor current signal is monitored by the microprocessor at sampled motor current signal output IFBK as an analog input channel. The signal may be used for closed-loop motor current control as well. In one embodiment, transistors (Q22 and Q23) are implemented as 2N7002 transistors that are industry standard transistors available from major silicon
30 manufactures. In this embodiment, resistor R110 is implemented as a 10.0 ohm resistor and capacitor C115 is implemented as a 0.1 microfarad capacitor.

FIG. 4 is a flow diagram illustrating a method **400** for controlling a brake motor. Method **400** may utilize one or more systems detailed in **FIGS. 1 - 3**, above. The present invention can also take the form of a computer usable medium including a program for configuring an electronic module within a vehicle. The program stored in the computer usable medium comprises computer program code for executing the method steps described in **FIG. 4**. Method **400** begins at block **410**.

At block **420**, brake motor information is received. In one embodiment, brake motor information includes brake motor voltage information and brake motor current information. In an example, brake motor current information includes link current information. In another example, brake motor current information includes motor current information. In one embodiment and referring to **FIG. 1**, brake motor controller **120** receives brake motor information from brake power motor driver **160**. In another embodiment and referring to **FIG. 1**, voltage sensor **130** receives brake motor voltage information from brake power motor driver **160** and current sensor **140** receives brake motor current information from brake power motor driver **160**.

At block **430**, a first brake motor voltage value and a brake motor current value are determined based on the motor information when the brake motor is active. In one embodiment, the first brake motor voltage value is determined by determining a first and a second active phase brake motor voltage values of the three-phase brake motor, and determining an absolute value of the difference of the first and the second active phase brake motor voltage values. In an example and referring to **FIG. 2** above, the two active phases of the three single-phase voltage outputs (DiagphA, DiagphB, and DiagphC) are determined and an absolute value of the difference of the two active phases results in the first brake motor voltage value.

In another embodiment, the brake motor current value is determined by sampling a DC link current, such as, for example as described in patent number 6,262,544 B1 issued on July 17, 2001 and titled FOUR QUADRANT MOTOR OPERATION USING
5 DC BUS CURRENT SENSING. In another example, brake motor current value is determined by sampling a DC link current as described in **FIG. 3**, above. In yet another embodiment, the brake motor current value is determined by directly measuring the stator winding current of the active phases.

At block **440**, a brake motor resistance value is determined based on the first
10 brake motor voltage value and the brake motor current value. In one embodiment, the brake motor resistance value is determined utilizing Ohm's law ($R=V/I$). In an example and referring to **FIG. 1** above, processor **150** determines the resistance value based on the first brake motor voltage value received from voltage sensor **130** and brake motor current value received from current sensor **140**.

15 At block **450**, a brake motor temperature value is determined based on the determined brake motor resistance value. In one embodiment, the brake motor temperature value is determined by comparing the determined brake motor resistance value to a database, identifying the brake motor temperature value associated with the brake motor resistance value, and receiving the brake motor temperature value from the
20 database. In an example, the database is implemented as a look-up table including an associated brake motor temperature value for each brake motor resistance value.

At block **460**, a brake motor control signal is produced based on the determined brake motor temperature value. In one embodiment, the brake motor control signal is produced based on the determined brake motor temperature value and control input
25 received in the form of a system control signal. In an example and referring to **FIG. 1**, processor **150** produces the brake motor control signal based on the determined brake motor temperature value and control input received via control input terminal (Input).

At block **470**, the method ends.

Additionally, method **400** may further include a diagnostic methodology. In one embodiment, the diagnostic methodology of method **400** includes determining a second brake motor voltage value when the brake motor is inactive and producing a motor
5 diagnostic voltage value based on the determined second brake motor voltage value. In an example, the diagnostic methodology is implemented as described in **FIG. 2**, above.

The above-described system and method for controlling a brake motor is an example system and method. The system and method for controlling a brake motor illustrates one possible approach for controlling a brake motor. The actual
10 implementation may vary from the package discussed. Moreover, various other improvements and modifications to this invention may occur to those skilled in the art, and those improvements and modifications will fall within the scope of this invention as set forth in the claims below.

The present invention may be embodied in other specific forms without departing
15 from its essential characteristics. The described embodiments are to be considered in all respects only as illustrative and not restrictive.